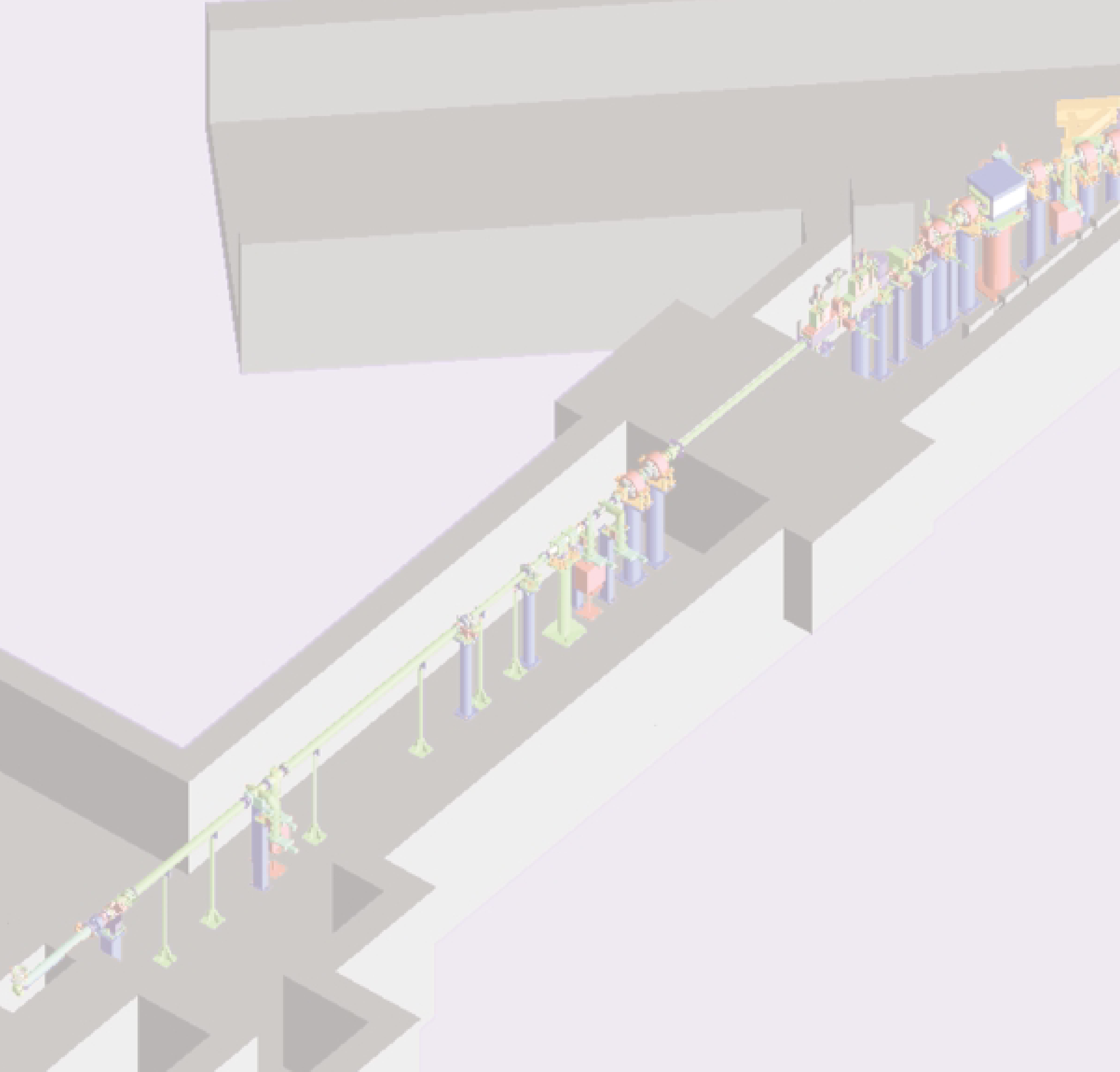
Special Projects



Short-Pulse Spallation Source Enhancement Project

P.S. Lewis (LANSCE Division)

The Short-Pulse Spallation Source (SPSS) Enhancement Project will significantly upgrade LANSCE capabilities by increasing the neutron source intensity and by constructing additional neutron scattering spectrometers. Because the facility improvements will support both the defense and basic research communities, this project is jointly funded by DOE DP and SC. DP is supporting accelerator improvements, which will increase the 800-MeV proton beam current delivered to the Lujan Center. SC is supporting the design and construction of new neutron-scattering spectrometers at the Lujan Center.

Accelerator Enhancement

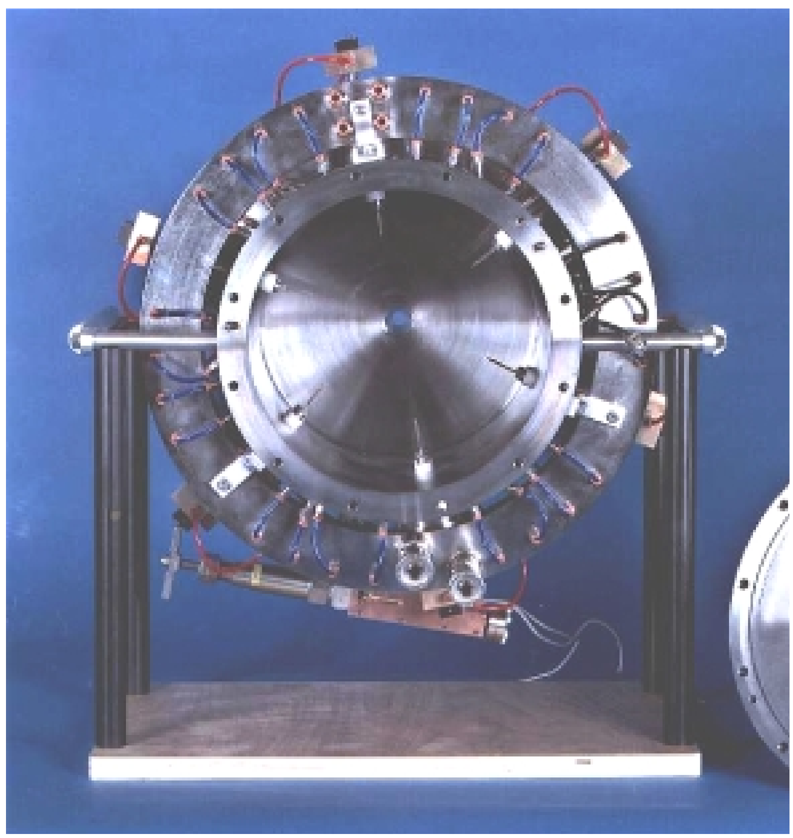
The primary technical goal of the upgrade is to increase the average proton current delivered to the Lujan Center spallation target to 200 μA at a 30-Hz repetition rate to provide 160 kW of power to the target. To achieve this performance goal, the following major modifications to the LANSCE accelerator facilities are being carried out.

- The PSR is being upgraded to handle higher accumulated charge levels. The upgrade includes a redesigned rf buncher and modifications to the ring and 1L transport line to control instabilities and to minimize slow beam losses.
- A brighter H^- ion source for the accelerator is being developed in collaboration with LBNL. In addition, the injector's 80-kV accelerating column and its high-voltage power and control systems are being upgraded to accommodate the new source.

Ion Source and Injector Upgrade. The ion source (Fig. 1) and injector upgrade includes

- development and fabrication of axial proof-of-principle, prototype, and final production sources at LBNL with a technical goal of 20 to 40 mA H^- current at an emittance of 0.4 to 0.8 π mm-mrad, 95% normalized;
- construction, instrumentation, and validation of the Ion Source Test Stand (ISTS) at LANL;
- development of a new 80-kV column to accommodate higher source current;
- upgrade of the injector high-voltage power and control systems to accommodate the new source and column;
- system testing prior to installation; and
- installation and commissioning.

Development and fabrication of the sources, column, and ISTS were completed in previous years. During 2000, the high-voltage power and control systems were completed and tested and are ready for installation. Extensive development efforts were carried on the ISTS to reduce source emittance, cumulating in a demonstrated 23 mA current at 0.8 π mm-mrad (95% normalized), which meets the SPSS project's technical baseline specification. Installation of the ion source upgrade is scheduled for 2002. For more information, see page 94.



↑ ***Fig. 1.*** *Photo of the new ion source designed and fabricated for LANSCE by LBNL.*

Proton Storage Ring Upgrade. The PSR upgrade includes

· a redesign and refurbishment of the rf buncher to increase its peak voltage from 12 to 18 kV (peak) and improve its reliability (Fig. 2),
· upgraded power and water utilities in the PSR,
· extensive PSR testing to identify means of controlling the PSR instability at accumulated charge levels of 6.7 μC and above,
· installation of multipole magnets and inductive elements in the PSR to control transverse instabilities,
· titanium nitride (TiN) coating of key PSR vacuum chamber components to reduce electron multipactoring, and
· improvements to the 1L transport line to reduce losses that contribute to background radiation levels in ER-1 at the Lujan Center.

↑ ***Fig. 2.*** *Refurbished rf buncher in the PSR.*

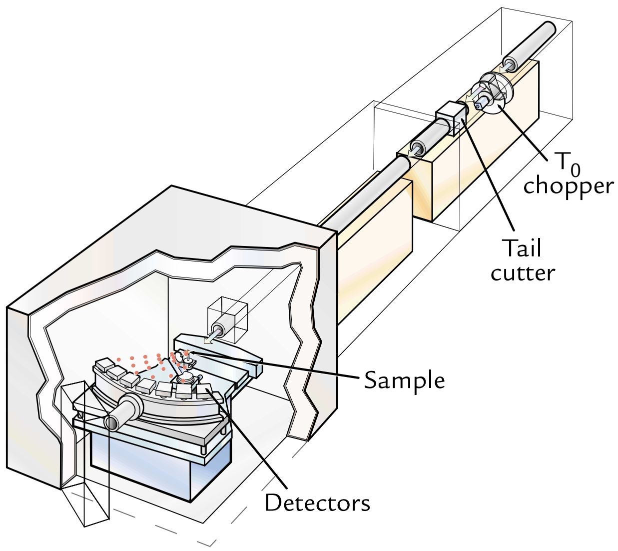
The buncher and utilities upgrades were successfully completed in prior years. In 2000, tests demonstrated control of the PSR to levels of up to 9.6 μC of accumulated charge. The design, installation, and commissioning of the PSR multipoles and inductors were successfully completed. Work on the TiN coatings has begun and will be completed in 2001. Work on the 1L improvements has also started. The PSR upgrades will be completed in 2001, and the 1L upgrades will be completed in 2002.

Spectrometer Development

The spectrometer development project will add three neutron-scattering instruments to the Lujan Center. The individual instruments are being designed and constructed by collaborative spectrometer development teams involving participants from federal laboratories, universities, and industry. One of the instruments is a structural biology spectrometer funded by OBER. OBES is funding the remaining two instruments. During 2000, the PCS, SMARTS, and HIPPO were under construction.

Protein Crystallography Station. The PCS is an OBER-funded neutron diffractometer designed for structural biology (Fig. 3). The instrument will be located on FP15 viewing a partially coupled high-intensity water moderator with beryllium reflector. The instrument will include a large position-sensitive two-dimensional detector, designed and fabricated by BNL, that allows horizontal and vertical scans. Construction began in 1999 with installation of the PCS mercury shutter. During 2000, construction of the beam line, cave, and electronics hutch was completed. Shielding construction was approved by the Lujan Center, and the instrument received first beam in December using a test detector from BNL. During 2001, the T_0 chopper and main BNL detector will be installed, and the instrument will be commissioned. (See also page 164.)

Spectrometer for Materials Research at Temperature and Stress. SMARTS is an OBES-funded powder diffractometer optimized to measure strain on both very large and small samples within a variety of sample environments (Fig. 4). The instrument will have two principal modes of operation—strain scanning and material testing. In the strain-scanning mode, SMARTS will be capable of measuring stress distributions in engineering components and other samples. In the material-testing mode, SMARTS will be capable of



↑ Fig. 3. *Protein Crystallography Station beam layout. In ER-1, a composite T_0/T_1 chopper and a (proposed) tail-cutting device remove unwanted high- and low-energy neutrons, thus optimizing the neutron beam for high counting rates and low backgrounds at reasonable instrument resolutions. The vacuum pipe is tightly surrounded by heavy shielding until it reaches the sample position where the shield opens up to a large cave in ER-2. In the cave, neutrons interact with atoms in the crystal sample, are scattered, and are detected by a large two-dimensional cylindrical area detector. A κ-circle goniometer moves the crystal and detector between about 30 different orientations. This feature enables all planes in the crystal to be brought into an orientation that will produce diffraction spots.*

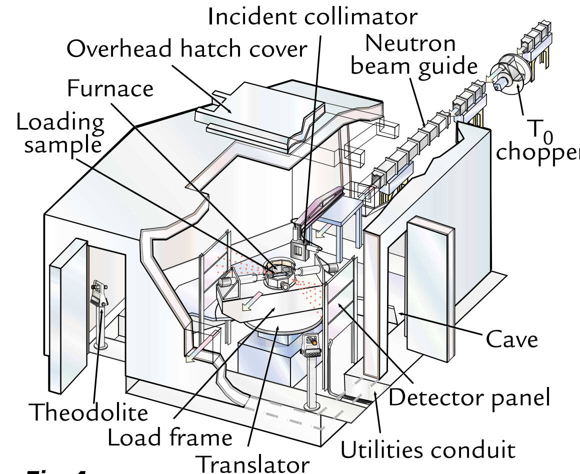


Fig. 4a

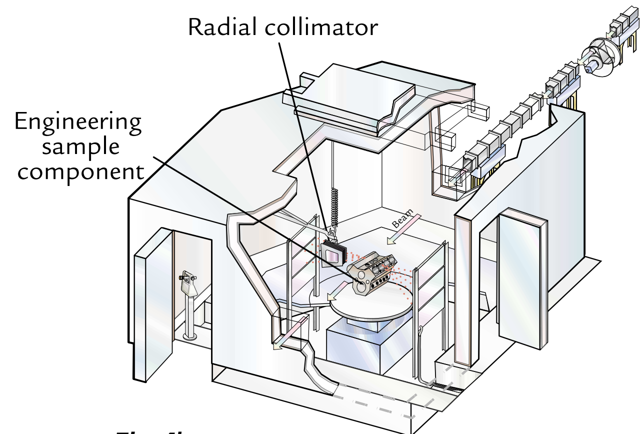
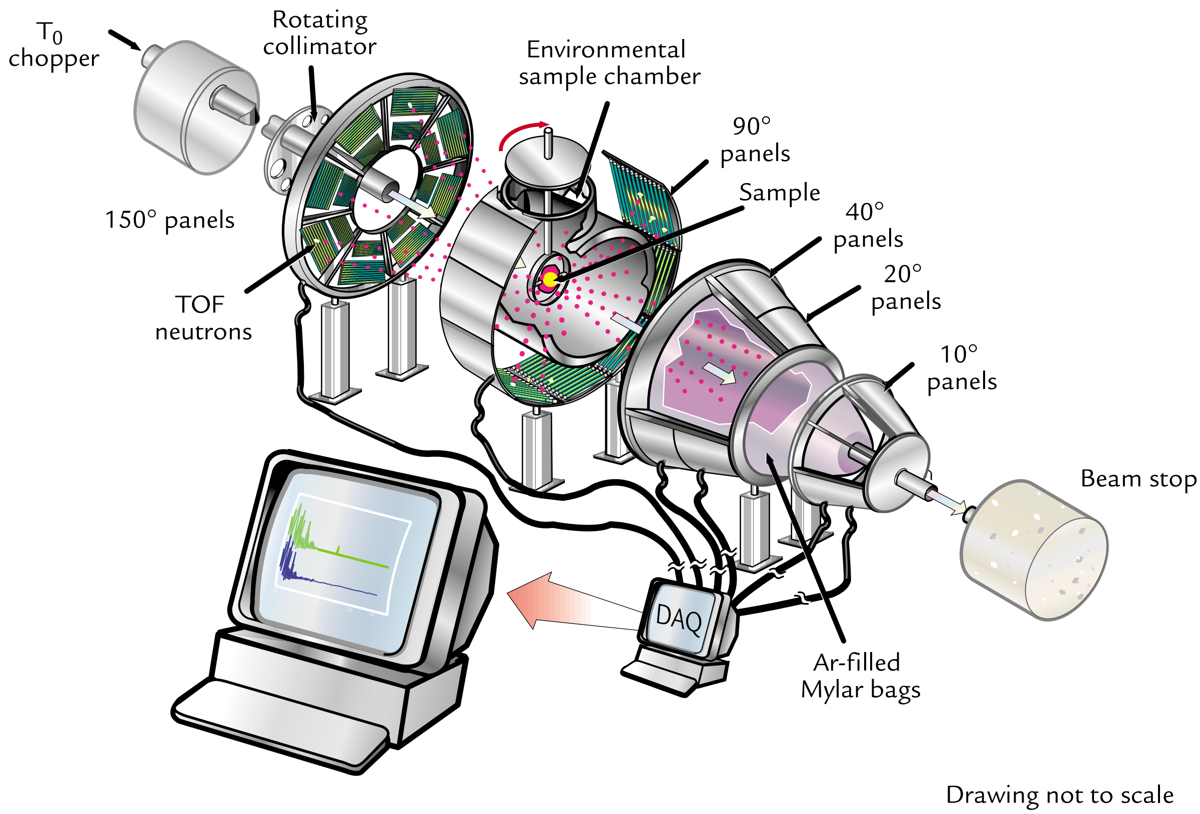


Fig. 4b

↑ Fig. 4. *SMARTS beam layout. Neutrons from the moderator pass through a series of collimating apertures before entering the neutron guide. In ER-1, a break in the guide accommodates a T_0 chopper, which removes fast neutrons and gamma flash that would otherwise contribute unwanted background. Slow thermal neutrons continue down the guide to the entrance of the SMARTS cave. On exiting the guide, neutrons pass to the center of the cave where some are scattered by the crystal structure of the sample to the detectors. Samples or ancillary systems are placed directly on the translator, which can accommodate up to 1500 kg, move in three orthogonal directions, and rotate about a vertical axis. Theodolites provide a precise optical triangulation and alignment capability for equipment or samples. Fig. 4a illustrates the load-frame-furnace suite in place. Note that there is no collimation between the sample and the detector. Fig. 4b shows a radial collimator between the detector and a generic engineering sample. When used with the incident collimation, selection of an appropriate radial collimator defines a sampling volume for spatially resolved measurements. (Note: Beam-line shielding is not shown.)*

carrying out measurements of materials under load, at high temperatures, and in controlled atmospheres. SMARTS is located on FP2 viewing a high-resolution water moderator. The instrument includes a neutron guide to enhance the flux on the sample, the capability of accommodating a sample with a total mass of at least 500 kg, and the capability of carrying out *in situ* strain measurements on samples at 180 kN and at 1500°C. Construction began in 1999 with the installation of the SMARTS mercury shutter. During 2000, substantial progress was made on construction and installation of SMARTS. The guide, cave, and translator were completed and installed. Shielding was fabricated, and installation began. The load frame and furnace set were completed and underwent acceptance testing at the factory. During 2001, beam-line construction will be completed, the T_0 chopper and electronics will be installed, and the instrument will be commissioned. A detailed report on SMARTS can be found on page 156.

High-Pressure Preferred Orientation Spectrometer. HIPPO is an OBES-funded high-intensity powder diffractometer designed for texture measurements (Fig. 5). HIPPO will have the capability to study samples at high pressure and high and low temperatures. The instrument is located on FP4 viewing a high-intensity water moderator, and it includes detector banks at (nominally) 150°, 90°, 40°, 20°, and 10° (1,384 detectors, 4.6 m^2) and a sample changer capable of rapid interchange of samples. Construction began in 1999 with the installation of the HIPPO mercury shutter. During 2000, substantial progress was made on construction



↑ ***Fig. 5.*** *Exploded view of HIPPO showing sample chamber surrounded by five conical three-dimensional rings of ^{3}He detector tubes in 10 atm. A white beam made up of pulsed neutrons of different energies (entering from the left) travels down a collimator to a chopper that cuts out very fast neutrons, allowing only slower thermal neutrons to continue down the FP to the bulk material contained inside a 29-in.-diam sample chamber. The neutrons interact with the lattice (crystal) structure of the bulk material, diffract off, and impinge on the detectors. Neutron diffraction is measured to ascertain how the energies or momentum of the neutrons changed after interacting with the atoms. (Note: FP and cave shielding are not shown.)*

and installation of HIPPO. FP4 was cleared, and beam-line and cave installation began. Fabrication and testing of the sample chamber, sample changer, and the detector and data-acquisition electronics were completed. During 2001, beam-line and cave installation will be completed; the T_0 chopper, sample chamber, sample changer, and electronics will be installed; and the instrument will be commissioned. (For more information on HIPPO, see page 160.)

Construction of a New Isotope Production Facility

R.C. Heaton, E.J. Peterson (C Division)

Radioisotopes, the unstable isotopes of chemical elements, dissipate excess energy by spontaneously emitting radiation in the form of alpha, beta, and gamma rays. This release of energy by radioactive decay makes radioisotopes a useful tool in medicine and research. Radioisotopes introduced into the body are taken up in different amounts by different organs and can be used for diagnosis and treatment of disease. Recording the distribution and concentrations of radionuclides as they decay provides clinicians with information about the presence, size, and shape of various abnormalities in body organs. Iodine-131, for example, is used to locate brain tumors, measure cardiac output, and determine liver and thyroid activity. Rubidium-82 is used in cardiology diagnosis. Carbon-14, a radioisotope used to date organic materials as old as 50,000 years, is also used to study abnormalities of metabolism that underlie diabetes, gout, anemia, and acromegaly. Aluminum-26 is used in biological studies into the causes of Alzheimers' disease and in material science experiments. Silicon-32, a byproduct of the technology used to produce aluminum-26, is used to study nutrient metabolism in single-cell phytoplankton plant life—most notably the diatom, which is a type of algae that researchers believe plays a major role in influencing climate change. Studying the uptake of silicon in diatoms provides information needed to precisely model the effects of greenhouse gases on global climate.

In industry, radioisotopes of various kinds are used for measuring the thickness of metal or plastic sheets and to examine manufactured metal parts for structural defects. Also, heat produced in the decay of radioactive isotopes can be converted into electricity for use as compact sources of electrical power in, for example, cardiac pacemakers and spacecraft. Other important isotopes used in biomedical, industrial, environmental, fundamental physics, and material-science research and development include arsenic-73, beryllium-7, bismuth-207, cadmium-109, gadolinium-148, niobium-92, rubidium-83, selenium-72, technetium-95m, titanium-44, vanadium-48, vanadium-49, yttrium-88, zinc-65, zirconium-88. A year-round, uninterrupted supply of these and many more important radioisotopes is now possible with the construction of the new IPF at LANSCE.

New Target Irradiation Capability at LANSCE

The radioisotope program at Los Alamos has been one of the more successful and visible ongoing endeavors in the production and distribution of isotopes nationwide. As an essential element of the nation's health care program, it depends on the Laboratory's ability to deliver key medical radioisotopes to customers on a year-round daily basis. LANSCE has supported the program by producing radioisotopes for more than twenty years. Without the production capabilities at LANSCE and other national and international facilities, DOE will not be able to meet the needs of its radioisotope customers. More than a billion dollars of installed and operational medical instruments that depend on these radioisotope supplies will be adversely impacted if these materials are not made available.

The production of radioisotopes at LANSCE traditionally took place when excess beam from the linac was used to irradiate targets located near the beam stop in experimental Area A. But a changing mission and new experimental program at LANSCE has led to facility and accelerator modifications whereby excess beam will no longer be available for radioisotope production in Area A. Meeting the continuing demand for radioisotopes from industry, research institutions, the medical community, academia, and government therefore necessitated the design and construction of a new IPF at LANSCE (Fig. 1). The completion and commissioning of this new target irradiation capability, at an estimated cost of $20 million, will ensure a dedicated year-round supply of radioisotopes when combined with similar isotope production capabilities at BNL and supplemented by international collaborations with TRIUMF (Vancouver, Canada), Institute of Nuclear Research (Troitsk, Russia), National Accelerator Centre (Faurve, South Africa), and Paul Scherrer Institute (Villigen, Switzerland). The IPF project was first initiated in November 1998. In 1999, a detailed design of the facility and equipment was completed, and facility construction began in February 2000. By November 2001, construction of the new IPF building will be complete. The facility will become operational in 2003.

One essential goal remains at the forefront of this nationally and internationally important project—to provide a state-of-the-art facility that will continue the production of medical isotopes at LANL. The main

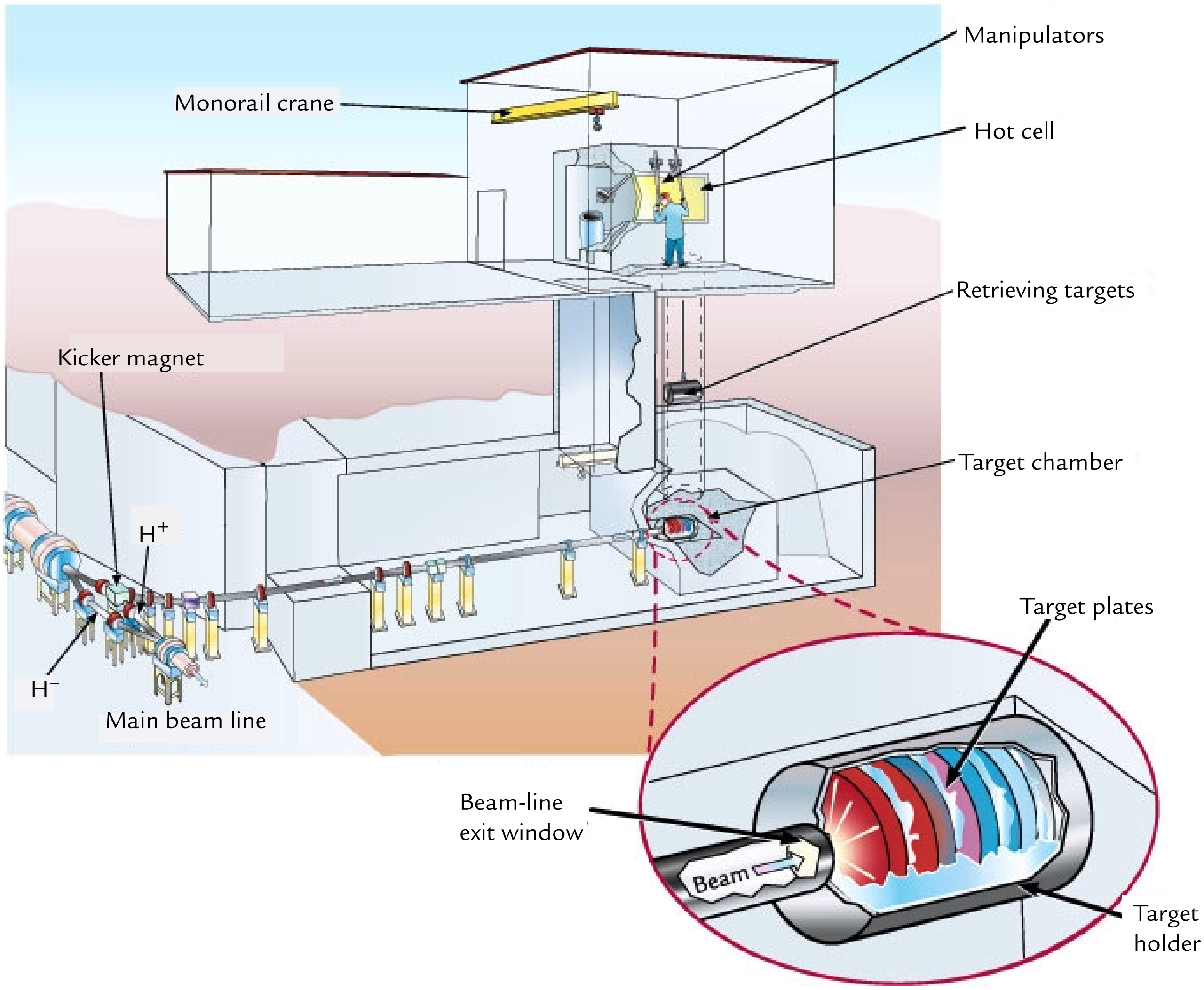


Fig. 1. *Artistic rendering of the IPF.*

systems of the new IPF will include upper- and lower-level building structures to house special IPF equipment, a new beam line that extends to the target irradiation area below ground (in the lower-level of the facility), and target equipment and a hot cell in the upper level of the facility to handle the irradiated targets. The scope of this project includes the design and construction of a beam-line tunnel and targeting area, the design and construction of an upper-level building to house mechanical and remote handling equipment, the design and construction of an accelerator beam line, the modification of one segment of the LANSCE accelerator, and the design and construction of target irradiation and remote handling systems. When complete, the IPF will follow a normal operating sequence that begins with loading targets into the beam-stop area and ends with shipping irradiated targets to a processing facility where radioisotopes are separated from the irradiated targets and prepared for distribution.

Innovative Target Insertion and Retrieval Operations

The LANSCE accelerator is made up of three components—an injector that accelerates a proton beam to 750 KeV, a drift-tube linac (DTL) that further accelerates the beam to 100 MeV, and a side-coupled cavity linac (SCCL) that further accelerates the beam to 800 MeV. The region between the DTL and the SCCL provides a transition zone where a 100-MeV proton beam can be extracted from the existing main beam line (Fig. 1). A fraction of the 100-MeV proton (H^+) beam is extracted and then deflected 45° by a new kicker magnet and a direct-current bending magnet. The extracted beam is transported through a new beam line to a radioisotope production target chamber located in the IPF's lower level (underground). (The undeflected proton beam continues into the SCCL where it is accelerated to 800 MeV for use in other beam lines.) The new beam line ends at the target chamber where the beam passes through an exit window and irradiates the target assembly—a stack of flat metal plates arranged in a holder along a horizontal center line of the beam (Fig. 1 inset). Spaces between the plates are filled with flowing water coolant to prevent the targets from melting and to absorb some of the proton beam energy. The front plate in the target assembly experiences nearly the full 100-MeV beam energy, whereas plates further back in the stack will experience progressively lower beam energies. As the beam passes through the successive layers of plates and water, it slows to a stop in the last plate. The cross-sections for the nuclear reactions needed to produce useful radioisotopes have resonances in the 20- to 100-MeV range. As such, several production reactions can be initiated simultaneously with the appropriate target materials, thickness, and arrangement.

A remotely operated target transport mechanism inserts and retrieves targets through a vertical shaft between the target chamber in the lower level of the facility and a hot cell in the upper level. This mechanism guides the target assembly between the target chamber and the hot cell and ensures that targets are in proper placement for irradiation. The hot cell provides a shielded working area where radioactive targets are remotely mounted, unmounted, and loaded into shipping casks using manipulators and a shielded viewing port constructed of leaded glass. Fresh targets and other small objects are brought into the hot cell through a shielded sample feed-through mechanism. The hot cell is shielded on three sides and on the top with concrete and steel shielding. The fourth side consists of a shield door, which provides access to the interior of the hot cell when necessary. Certified casks are used to ship irradiated targets from the IPF to the chemical processing facility. An overhead monorail crane transfers the casks to and from a truck that is backed into the facility through a roll-up door.

Factors Affecting Radioisotope Production

When the proton beam impinges on the first plate of the target assembly, several things happen simultaneously. Some of the protons interact with the target nuclei to form the product nuclei. Take for example the irradiation of zinc metal or oxide to produce copper-67—an important radioisotope used in lung-cancer research and in monoclonal antibody labeling. (Monoclonal antibodies are pure, uniform, and highly sensitive protein molecules produced by genetic-engineering techniques for use in medicine to diagnose and combat a number of diseases.) Sufficiently energetic protons will react with zinc-68 nuclei in the target, resulting in the absorption of one proton and the emission of two others. This reaction results in the formation of copper-67 nuclei. The factors that determine the amount of copper-67 produced in this reaction include (1) the number of zinc-68 atoms placed in the beam, (2) the number of protons per unit time that strike the target, (3) the probability that a proton will actually collide effectively with a zinc-68 nucleus and give rise to the desired nuclear reaction, and (4) the duration of the bombardment. Maximizing all these factors produces the best yield of copper-67.

Protons that do not participate in the nuclear reactions are impacted in two important ways. First, the protons lose energy as they pass through the targets and the cooling water. Second, they are deflected from their incident path, resulting in a broadening of the beam. The new IPF will take advantage of the first phenomenon by configuring the target stack to give the desired energy range in one or more successive targets. Targets at the front of the stack will be used to degrade the beam energy to the desired levels for subsequent targets. (The beam energy range in a target is an important factor in maximizing the probability of the desired nuclear reaction.) In this way, several targets can be irradiated at different energies simultaneously, thus maximizing the efficiency of the facility.

The new IPF target assemblies will be thick enough so that the beam energy will be degraded to zero within the last target in the assembly. With all of the beam energy deposited into the target materials, the target assembly must be cooled (as described above) to keep the targets from melting. The cooling is accomplished by circulating cooling water between the target plates. The thickness of the water channels is important not only in achieving effective heat transfer but also in obtaining the desired amount of beam energy degradation for subsequent targets.

One consequence of the deflection of protons noted above is that even a narrowly mono-energetic beam will acquire an energy spread. The extent of this energy spread will depend on the nature of the incident particles, the nature of the target material, and the physical thickness of the target. The FWHM of the energy distribution is a measure of this energy straggling, and it increases with the depth of the beam in the target assembly. This beam energy spread may limit the control that can be exercised over nuclear-reaction channels in targets located at the back end (low energy) of the target stack.

Many factors must therefore be considered in relation to irradiating targets to yield useful quantities of radioisotopes. Beam energy, beam current, desired nuclear-reaction cross sections, undesired nuclear-reaction cross sections, target configuration, target mass, and stopping power are all critical parameters. Ultimately, production yields from specific target configurations are best determined empirically. The new IPF will provide an important research capability for determining such yields.

With the construction of the new target irradiation capability at LANSCE, Los Alamos will continue its twenty-year-old tradition of producing and distributing a rich variety of radioisotopes for medical, industrial, environmental, and other tracer applications.

Accelerator Systems for the Advanced Hydrotest Facility

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The first static images of the bones in a human hand and the interior of metal objects were taken by Wilhelm Roentgen, who in 1895 revolutionized diagnostic techniques with his discovery of the x-ray—a penetrating, electrically uncharged form of radiation. In the decades that followed, x-rays were used largely for diagnosing and treating fractures and for locating foreign bodies (such as bullets in wounded soldiers) during periods of war. The development of more advanced methods to accurately record the subsurface features of objects led to innovative techniques in radiography using x-rays, gamma-rays, and charged particles as imaging probes. These techniques were applied to a wide range of medical, industrial, and scientific problems—most notably in the diagnosis and treatment of disease; in the nondestructive inspection of castings, welds, and engineering structures; and in the magnification of microscopic objects.

Toward a Safe and Reliable Stockpile

By the mid 1990s (nearly 100 years after Roentgen's discovery), hydrodynamic radiography—a technique that captures instantaneous multi-frame images of fast dynamic events—became a new thrust of the stockpile stewardship mission to ensure the reliability, security, and safety of the nation's nuclear arsenal in the absence of testing. In response to this important mission, Los Alamos has created the Dual Axis Radiographic Hydrodynamics Test (DARHT) facility to create x-ray bursts that form shadow images of events related to the detonation of primaries—the subassemblies in weapons that initiate the nuclear process. More recently, Los Alamos has formed a collaboration with LLNL to design an AHF that carries the radiography concept to the next stage in measurements relevant to the reliability and safety of primaries more completely and accurately than any other method currently available. The AHF will use magnetically focused, high-energy protons to radiograph, in multiple frames, test objects under compression (implosion) in very rapid succession to produce three-dimensional images with CT—a method that re-constructs the internal structure of an object from a series of cross-sectional images taken through the object at 15° intervals in a horizontal plane. With this advanced technology, researchers will be able to accurately track the evolution of dense thick objects driven by high explosives and thereby obtain information on the physical properties and behavior of materials in the nuclear weapons stockpile, including changes caused by aging.

In the past, weapons physics was addressed through a combination of underground weapons tests, hydrodynamic tests (or hydrotests) using x-ray sources, and computer simulations. The Comprehensive Test Ban Treaty ended underground weapons tests, leaving hydrotests and simulations as the only tools available for certifying weapons performance. Current weapons simulations, however, need to include three-dimensional effects that involve manufacturing defects, aging, and safety, and hydrotests are needed to validate these simulations. Currently, the DARHT facility uses pulsed x-rays to form two simultaneous shadow images of dynamic events as a means of evaluating the safety and reliability of the aging nuclear stockpile. However, high-energy protons can penetrate thicker, more dense objects than can x-rays. They can also be detected with high efficiency at more than one location by multiple detector layers because the beam is not disrupted appreciably by passage through each detector. In addition, they can be focused by magnetic lenses to produce high-resolution images that can be further analyzed for material identification and thickness.

With support from LANSCE, researchers are performing single-axis studies in Area C to demonstrate the viability of PRAD as a tool to meet the data needs of the weapons program, to help researchers develop better PRAD-imaging technology, and to provide a test bed for the overall advanced technology needed for a new AHF. To date, PRAD has been demonstrated at 800 MeV and 24 GeV and has achieved material identification. A small dynamic radiographic facility has been successfully operated in Area C where data obtained in recent experiments has been used to characterize high-explosive properties.

A multi-disciplinary group from LANSCE and other divisions throughout the Laboratory is working to exploit this advanced technology through engineering development and experimental activities leading to a conceptual design of an AHF facility. Extensive pre-conceptual design of the accelerator systems has been accomplished. Promising prototypes of detector systems that will achieve high-resolution-image capture at the required rates are currently under development.

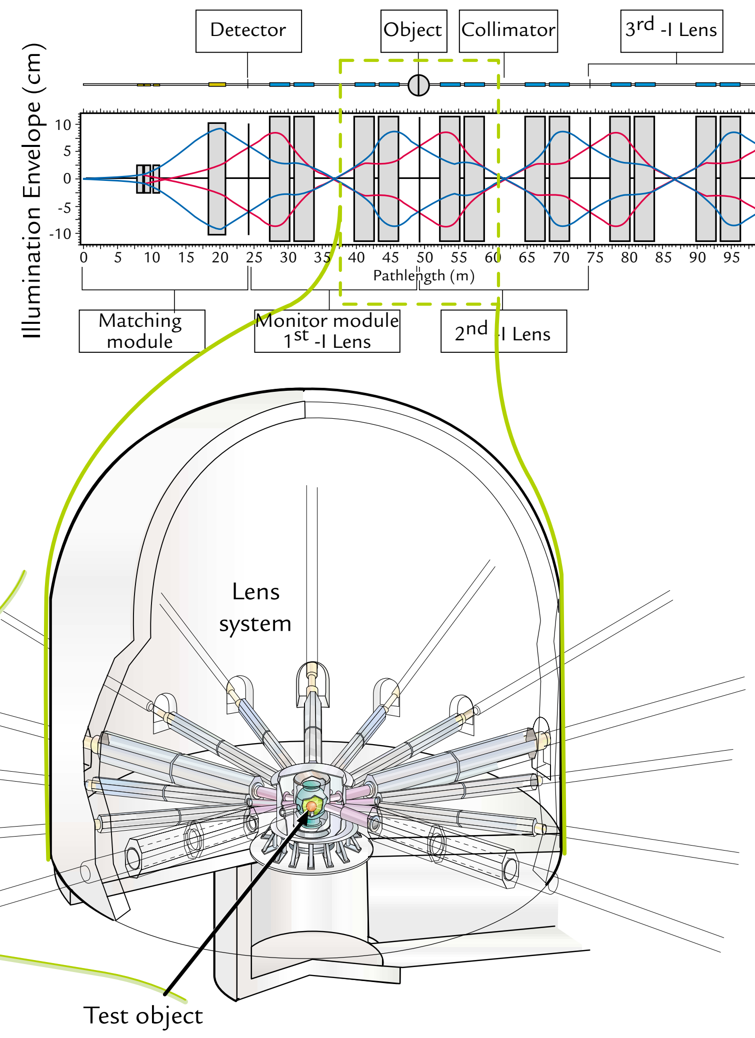
Additionally, advanced containment systems designed to confine the explosive force of the test object and to prevent environmental release are being explored with support from LLNL. Further design efforts will refine the optics, magnet, and balance-of-plant designs needed for a better assessment of costs and schedules. By the end of the decade, an operational AHF will be needed not only to certify the nuclear stockpile but also to attract and keep a new generation of designers who can assimilate the knowledge base of those with experience in underground nuclear tests. Although LANSCE is a possible site for the AHF, its actual location will be selected after a public National Environmental Policy Act and formal site-selection process by the DOE NNSA.

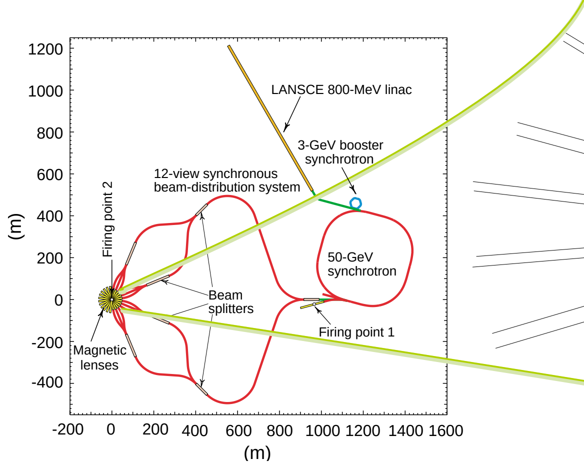
Each extracted macropulse is approximately 20 ns long and is split twelve times in a complex transport system and focused on a test object. A novel arrangement of quadrupole (magnetic) lenses focuses protons scattered from the object onto detectors, which electronically capture instantaneous images of the object and produce a transmission radiograph. The essence of the PRAD technology is in its lens-based camera system (described below in the section entitled *Innovative Lens System Renders Accurate Dynamic Images)*.

The incident protons in PRAD experiments undergo a number of effects as they interact with a test object. Consequently, these effects—the most important of

Design Scheme for an Advanced Hydrotest Facility

The AHF will require a time sequence of multiple radiographic images using a proton beam produced by a 50-GeV synchrotron. The synchrotron is loaded with up to 3 x 10^{13} 800-MeV protons in 20 pulses, each produced in one macropulse from the LANSCE linac, via a booster synchrotron that first accelerates the proton beam to 3 GeV (Fig. 1). Beam is extracted from the synchrotron in up to 20 macropulses with a time sequence appropriate to the application.





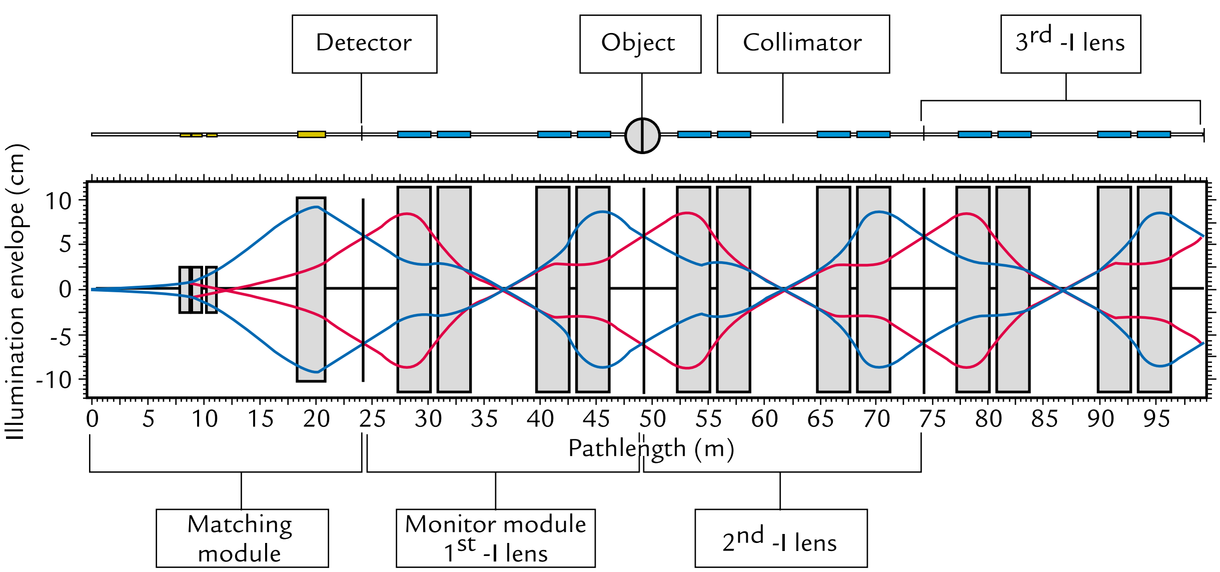
↑ **Fig. 1.** *Schematic and three-dimensional drawing of one of the AHF accelerator design options. Distances along the axes are in meters. The transport configuration is termed synchronous because the paths to the target are of equal length. Asynchronous versions, for which the line lengths are unequal, have been considered, among a continuum of options. An additional firing site with only one line just after the synchrotron is likely for phased and alternative operation.*

which are small-angle multiple Coulomb scattering (MCS), energy loss, and attenuation through nuclear processes—will allow researchers to identify the material that makes up the test object and determine its thickness. In MCS, protons passing through the test object interact with the electrons surrounding the atoms that make up its matter. These protons are deflected by the interactions to scatter at small angles and lose energy. (For instance, 50-GeV protons passing through a 6-cm tungsten target will scatter at about 0.1° in all directions from an initial point and will lose an average of about 200 MeV in energy.) In addition to MCS and energy loss, protons can also be absorbed by nuclear collisions that further attenuate the number of protons in the beam. (The 6-cm tungsten target mentioned above will attenuate the beam by about a factor of two.)

Innovative Lens System Renders Accurate Dynamic Images

For many applications, a series of pulses spaced at the ring period of 5 µs are extracted to view the initial stages of an implosion. Later in the implosion, as higher time resolution is required, the pulse extraction will be timed so that pulses reach the object with a 200-ns spacing. During transport to the target, each pulse is split in half twice and then into thirds by a wire septum at the splitters for simultaneous arrival (within about 15 ns) of each portion at the test object (see Fig. 1). This scheme relies on equal-length paths for each portion of the split pulse. An alternative system for routing the beam line is under consideration as well. In this scheme, the times for the beam paths differ by several hundred nanoseconds after the second line division. Therefore, for all pulses to arrive simultaneously at the test object, a later pulse must be extracted from the synchrotron and diverted to the shorter beam line by a pulsed magnet. This scheme will require twice the number of pulses in the synchrotron, a faster rise-time extraction kicker for the ring, and loss of pulse-sequence versatility and a more complex timing scheme than that envisioned for the all-paths-of-equal-lengths configuration.

After the final split, each beam portion enters a lens section (Fig. 2) where it is first spread out in angle and expanded by a pair of quadrupole lenses labeled "matching module." At this point, the beam is characterized for intensity distribution and appropriate focus. It is then focused, one to one, onto the test object by a four-element lens system, known as a negative identity lens (-I lens), that comprises the monitor module. Passage through the test object scatters and attenuates the beam depending on the material composition and thickness of the object. An inverted image is formed after the second -I lens, and a second image is formed after the third and final -I lens. Creating two images in this manner exploits an important characteristic of the -I lens—that is, at the lens midpoint an angular focus is formed. At this point, collimators (which in radiography are essentially an arrangement of absorbers) may



↑ Fig. 2. *A lens system designed for AHF. The boxes in the figure are quadrupole lenses. The colored lines show beam envelopes in the horizontal and vertical planes.*

be inserted to limit (define) the beam angular spread reaching the image as required for the specific application. A collimator inserted in a -I lens at the angular focus eliminates the component of the beam with large scattering angles, enhancing the image contrast for parts of the object that scatter little. Conversely, a negative collimator (e.g., a cylinder placed in the path of the beam) placed at this point eliminates the component of the beam scattered into smaller angles.

Material identification is accomplished by looking at the object through appropriate collimator openings. By placing two lenses in series, we can obtain two images that can be used to determine the material composition of the object. For many applications, the collimator at the angular focus is positioned wide open so that all beam within the lens acceptance coming out of the object arrives at the first image plane. In the second lens, a collimator eliminates protons that have large multiple scattering angles. By doing a careful comparison of the two images, we can determine the density and atomic number of the material (and hence derive its identity). This comparison is particularly important in assessing the composition of material mixtures arising from an implosion, as well as in determining the implosion shape. Further important parameters, such as criticality, may be derived from the data. CT reconstruction using data from all twelve axes then provides a three-dimensional assessment of the object's material composition and the size of implosion details, including perturbations and asymmetries in its motion. The AHF will apply two types of lens systems—one with a large 19-in. beam bore (inside diameter of the beam pipe) and one with a smaller 9-in. beam bore capable of higher spatial resolution than that of the larger beam bore. Other considerations for the system design include choosing between superconducting and normal-conducting magnets for the elements. Here superconducting magnets are individually more expensive but use less power. For the lens systems, use of superconducting magnets is almost compelling to avoid a peak-power consumption of nearly 80 MW. Many other tradeoffs, including energy-storage options and siting, are to be made regarding system configuration and operating parameters. Recent decisions by the DOE have resulted in enhanced funding for the AHF project, which is currently preparing for conceptual design work to begin in 2002.

From the first static images taken of the bones in a human hand to the three-dimensional imaging of objects in motion, techniques in radiography have come a long way. Now with the nation's nuclear arsenal at issue, we are witnessing an explosion of ideas and new designs that will eventually lead to the construction of the first advanced hydrotest facility dedicated to yielding precise and clear images of dynamic events. The AHF extends capabilities of the DARHT facility to higher resolution and, with its innovative lens system, to material identification, thus providing a unique assessment of weapons-primary parameters.